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F-16 AI/VVI EVALUATION: A COMPARISON OF FOUR CONFIGURATIONS

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The experiment Evaluated the effects of four different F-16C cockpit configurations on pilot's objective, subjective, and physiological responses in a simulated Instrument Landing System (ILS) approach. The four configurations were displayed by combining one of two Attitude Indicators (AI) and one of two Vertical Velocity Indicators (VVI). Following is a list of the four instruments: An AI with raw ILS data, an AI with Flight Director steering, a moving pointer VVI, and an improved tape VVI. Seven pilots flew 40 simulated ILS approaches each. Both performance and subjective data were in agreement in suggesting less pilot workload when the aircraft was equipped with Flight Director AI. The results were not conclusive in selecting one VVI over the other. However, it appears that a configuration of an AI with Flight Director steering commands along with a moving pointer VVI could lead to the most efficient ILS approach performance.

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INTRODUCTION

In two communications from TAC/DR, Langley AFB, the observation was made that certain F-16 heads-down flight instruments need improvement. The F-16 C/D Vertical Velocity Indicator (VVI) provides poor utility in the instrument approach environment. The messages also noted that Attitude Indicator (AI) display in the F-16 is cluttered when the Instrument Landing System (ILS) is selected. As a result, the F-16 AI is difficult to fly accurately during precision instrument approaches. The VVI moving tape display does not enable the pilot to rapidly assess vertical velocity, nor can he readily evaluate trend information. The Attitude Indicator sphere had been downscaled because of cockpit space limitations, however the size of the miniature aircraft symbol and ILS glideslope/localizer deviation bars were not correspondingly reduced. The result was a cluttered ILS display and a head-down attitude presentation that is difficult to fly precisely. Both messages concluded with the statement that alternative flight instrument configurations need to be addressed, and one stated a need for the addition of Flight Director steering to the AI.

A further message, sent by HQ/AFSC, in agreement with the TAC/DR messages, requested that the F-16 System Program Office assess the concerns of the VVI/AI inadequecies and provide specific design alternatives, including implementation advantages and disadvantages.

In April 1987, ASD/YPDT approved a Crew Station Design Facility (CSDF) evaluation for the assessment of AI and VVI alternatives and Flight Director steering in ILS approaches for the elimination of the problems with F-16C/D AI and VVI instruments.

Beginning in mid-April 1987, the CSDF F-16C flight simulator was reconfigured to provide the capability for user pilots (TAC) to evaluate the relative merits of command steering on a head-down Attitude Director Indicator (ADI) in lieu of raw deviation data on the production AI and the use of a moving pointer VVI in lieu of a modified, production moving tape display.

INTRODUCTORY NOTE: REPORT TERMINOLOGY

The term "Attitude Director Indicator" refers to an Attitude Indicator with some form of Command Steering. For this reason, the current Attitude Indicator used in the F-16 will be referred to as the Attitude Indicator with raw ILS data or RD, rather than the misnomer, Attitude Director Indicator. The experimental Attitude Indicator with Flight Director steering will be referred to as the FD. The term "Attitude Indicator" (AI) will be used to reference Attitude Directional Indicators and Attitude Indicators in general.

Vertical Velocity Indicators, in general, shall be referred to as VVIs. The current F-16 Improved Tape VVI shall be referred to as the IT. The locally manufactured experimental Moving Pointer VVI shall be referred to as the MP.

OBJECTIVES

This evaluation was conducted to assess AI and VVI alternatives and the effect of Flight Director steering on ILS approaches in accordance with HQTAC, PACAF, AFSC, and HQUSAF messages and ASD/YPDT direction.

Specific objectives were:

1. To validate and quantify improvements in approach precision, pilot workload and safety to be gained by providing standard Flight Director steering commands for ILS approaches in the F-16.

2. To evaluate the merits of displaying vertical velocity in a standard, moving pointer/fixed scale format (the MP) as compared to the F-16 fixed-pointer/moving scale (the IT) through user pilot performance and opinion.

3. To obtain user pilot performance data and opinions on modifications to AI pitch and bank steering bar width, line thickness, etc. on the test ADI as compared to the F-16 Attitude Indicator.

METHOD

APPARATUS

Experimental Facility The evaluation was conducted in the Crew Station Design Facility (CSDF), an Air Force flight simulation facility which belongs to the Aeronautical Systems Division (ASD) of Air Force Systems Command, at Wright-Patterson AFB, Ohio. The facility is used to conduct human engineering and system design/mechanization studies in support of a variety of System Program Offices (SPOs). Figure 1 is a diagram of the CSDF simulator area; Figure 2 is a schematic of the F-16 simulator system.

F-16 Simulator. The F-16C (shown in Figure 3) simulator was constructed using a salvaged single-seat F-16 cockpit, truncated in front of the forward portion of the windscreen, and approximately fifty seven inches behind the canopy hinge. The undercarriage has been removed, and the floor panel section sits on small cannister-type wheels. The simulator does not employ a motion base. The cockpit controls and displays are configured to the F-16C Multi-National Staged Improvement Program (MSIP) Block 40 design. This all-digital design includes two 4 x 4-inch Multi-Function Displays (MFDs), a Wide Field of View (WFOV) raster video Head-up Display (HUD), an Integrated Control Panel (ICP), a Data Entry Display (DED), Hands-on Throttle and Stick (HOTAS) controls, centralized flight instruments, and the LANTIRN avionics suite (terrain-following radar, radar altimeter, FLIR, etc.). The side control stick, throttle, and flight controls are actual F-16 components. All of the other instruments, controls, and displays with the exception of the test FD are simulated using locally available equipment. The aft section of the simulator, the area formerly occupied by fuel cells, now contains the microprocessor racks which encompass the Advanced Simulator Technology (AST) interface. The microprocessors operate the controls and displays, while two fifty-pin ribbon cables connect the simulator to the

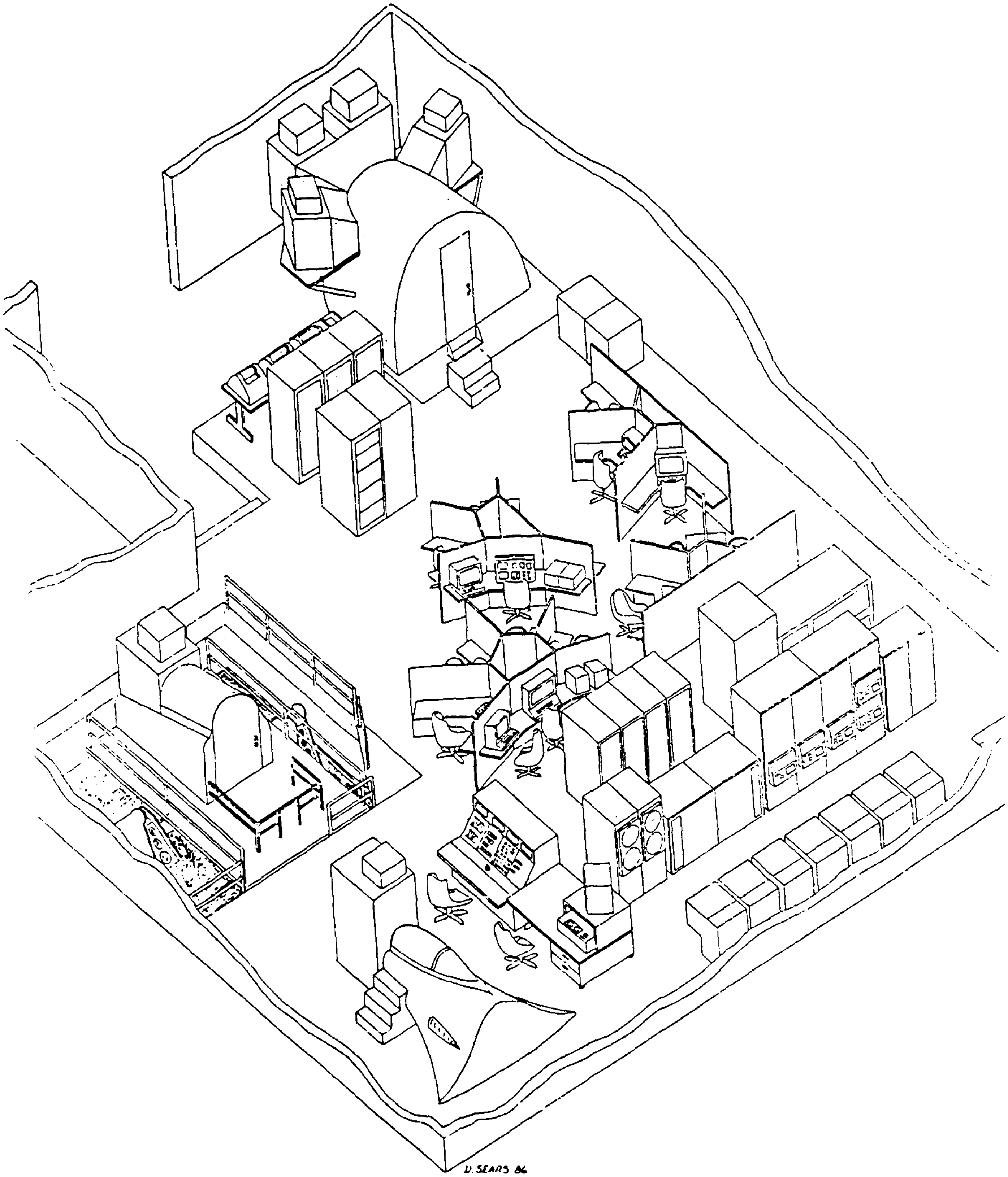

Figure 1. Crew Station Design Facility simulator area.

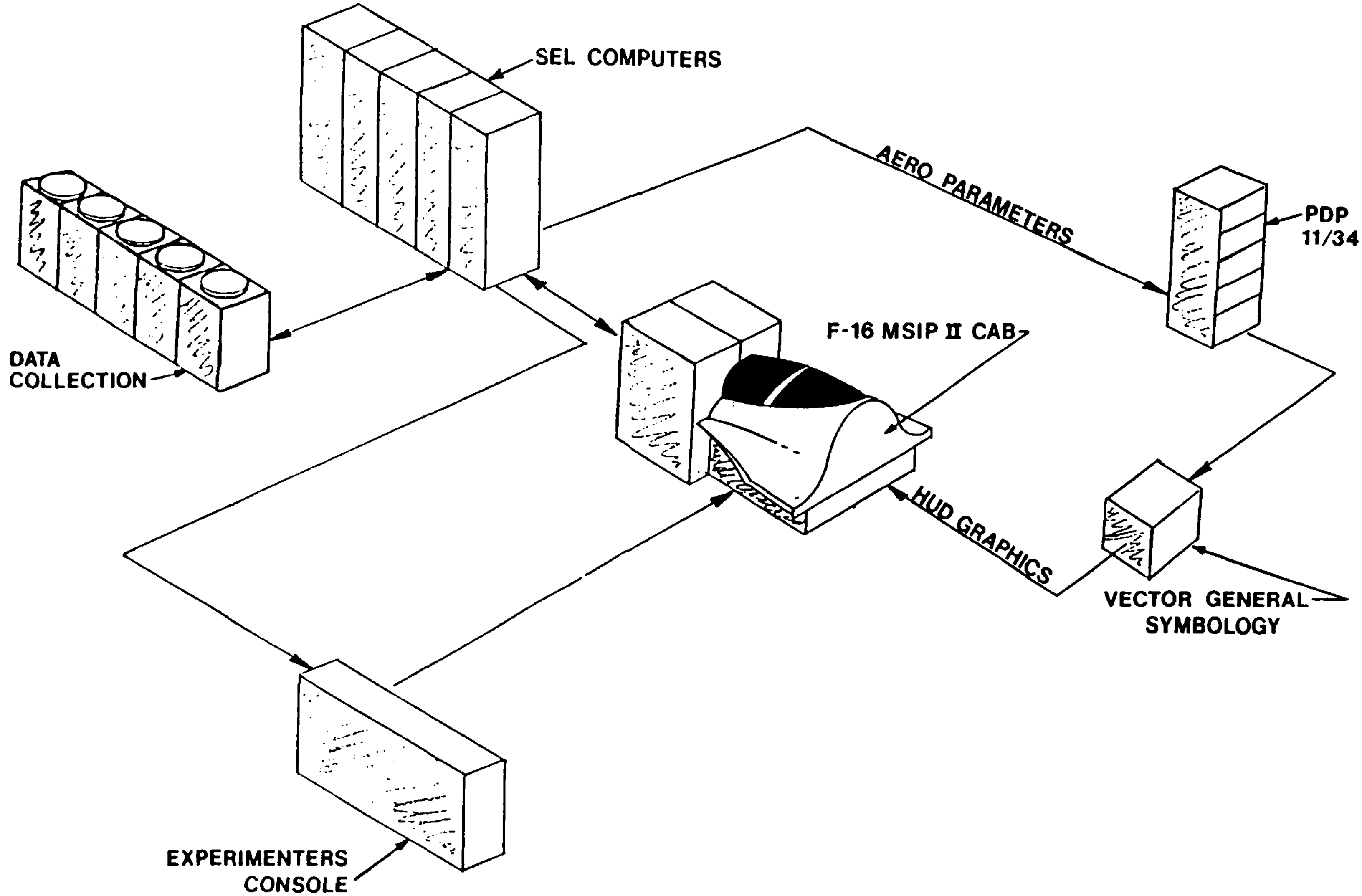

Figure 2. Schematic of the F-16C simulator.

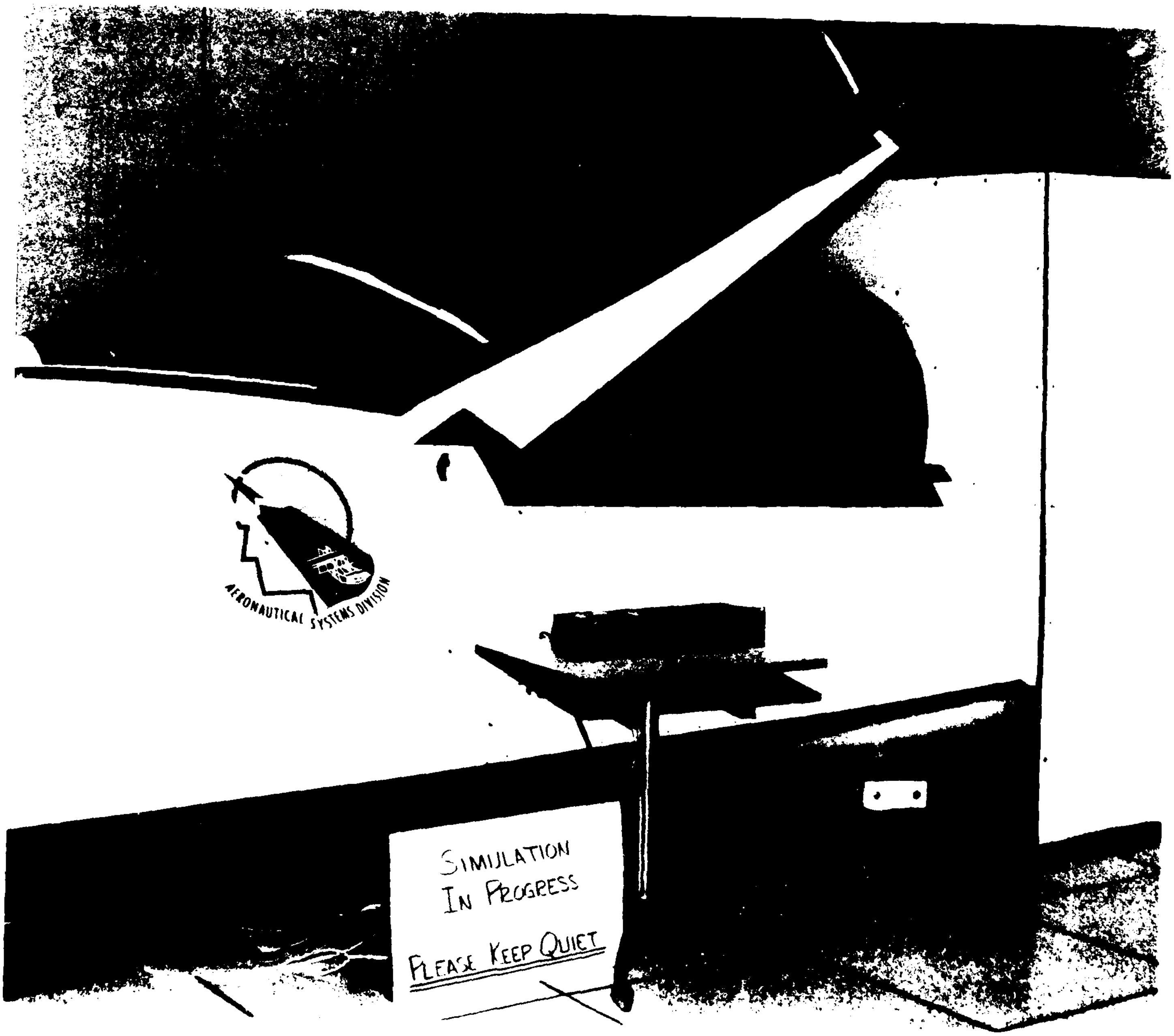

Figure 3. F-16C Simulator.

mainframe computers which perform the aerodynamic calculations. The combination of F-16 real and simulated instrumentation, the fully operational control and displays, the realistic visual system and HUD, and the actual cockpit, work together to create a high-fidelity replica of the F-16 MSIP cockpit. The aerodynamic model is the same one that is used for aircrew training, and its validity has been demonstrated in a number of prior experiments.

1. Display Configurations. Four configurations were used in the evaluation (see Figure 4): 1.) a baseline using the Block 40 head-down displays, including the latest F-16 modified tape VVI (IT) and the current Attitude Indicator with raw ILS data shown on the steering bars (RD) (shown in Figure 5); 2.) a configuration with the RD and an experimental moving pointer VVI (MP) (shown in Figure 6) ; 3.) a configuration with an experimental Attitude Directional Indicator with Flight Director steering (FD) and the IT (shown in Figure 7); and 4.) an all-modified display configuration using an experimental Attitude Directional Indicator with Flight Director steering (FD) and

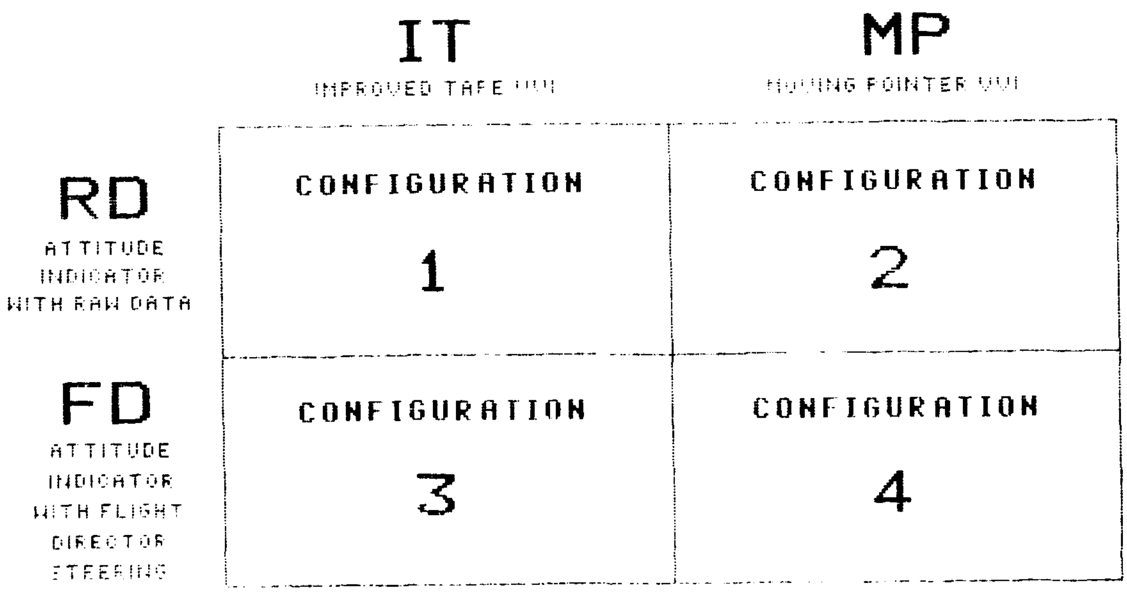

Figure 4. The four instrument configurations used in the evaluation.

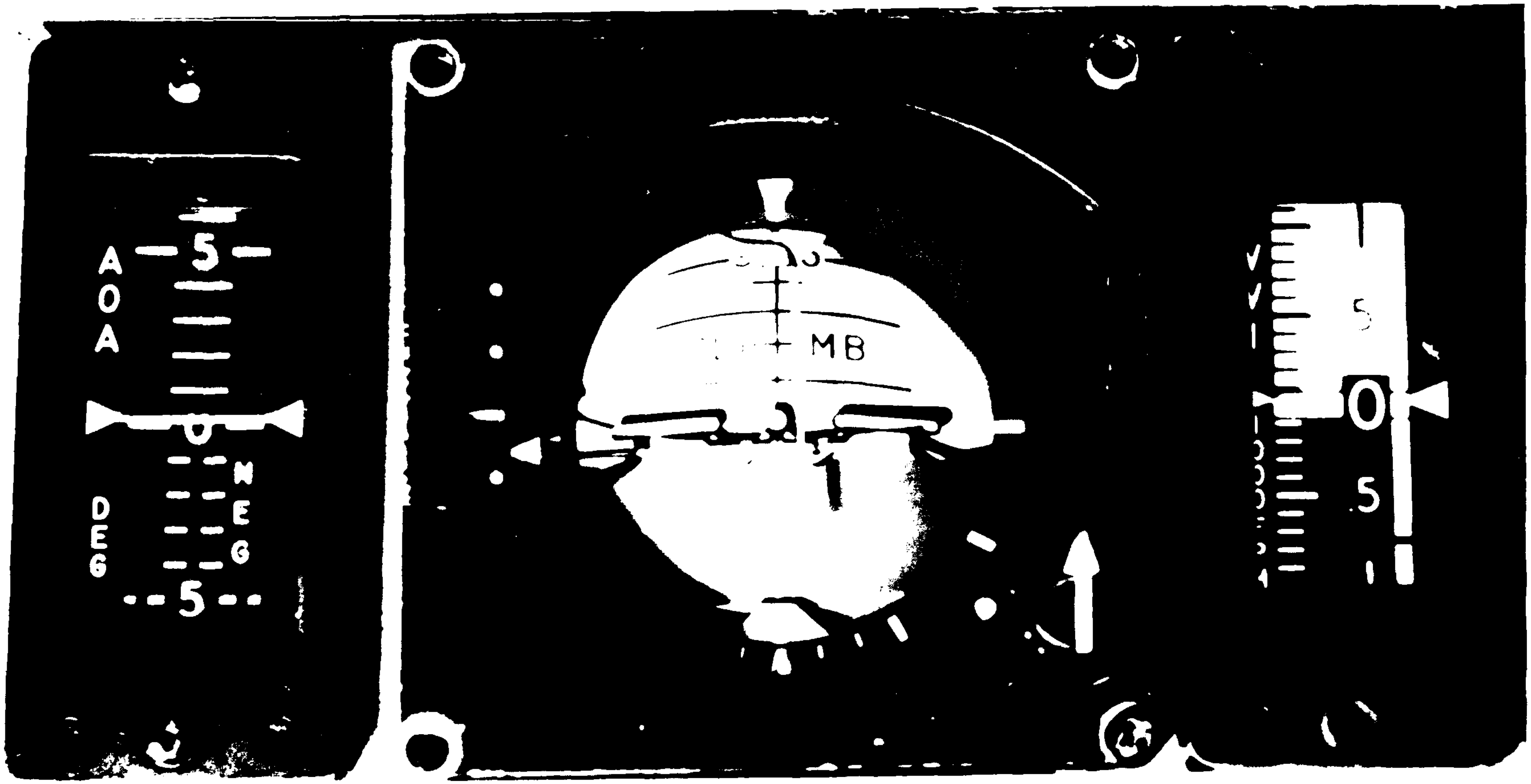

Figure 5. Configuration 1: Attitude Indicator with Raw ILS Data and Improved Tape Vertical Velocity Indicator.

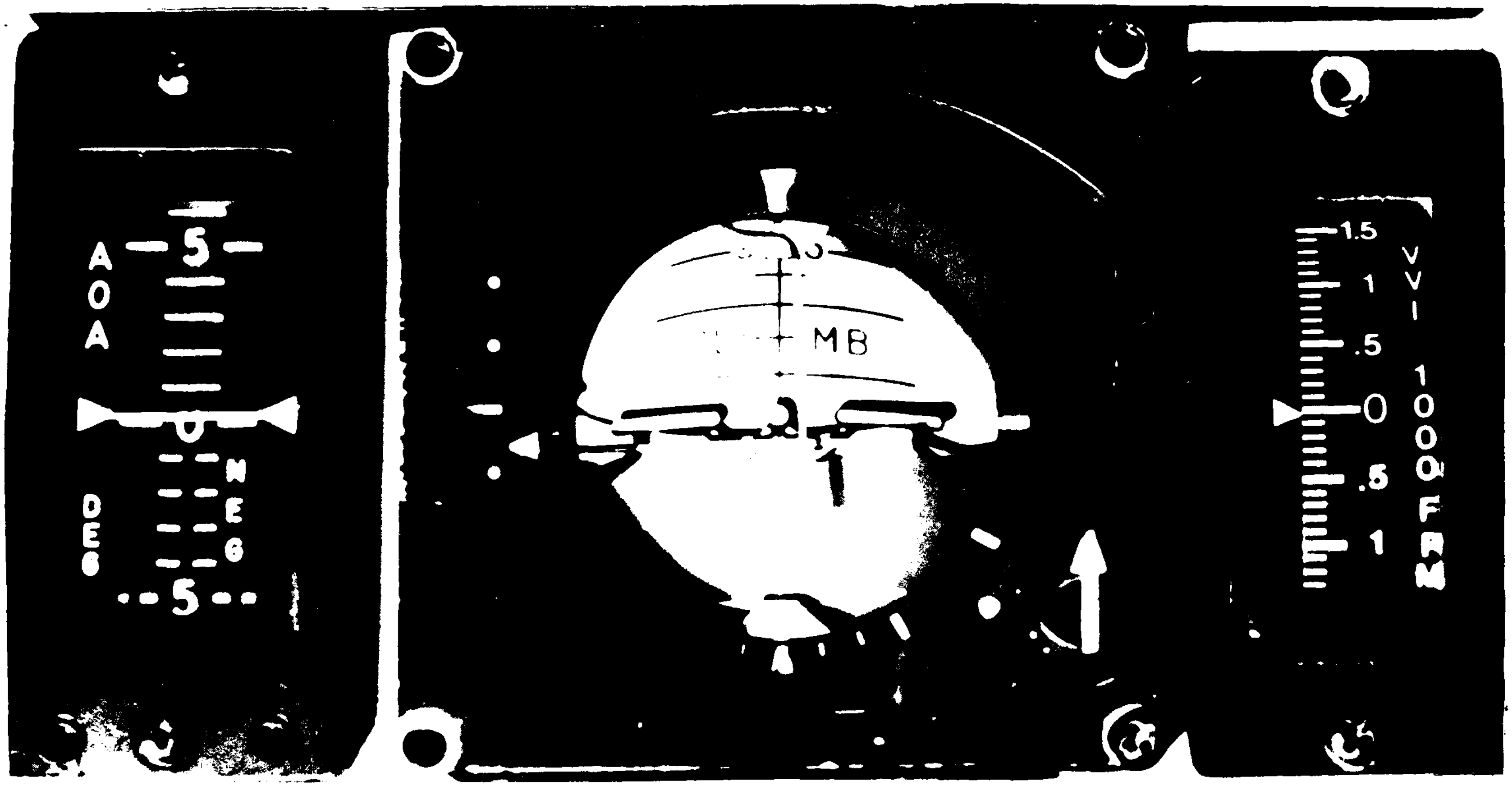

Figure 6. Configuration 2: Attitude Indicator with Raw ILS Data and Moving Pointer Vertical Velocity Indicator.

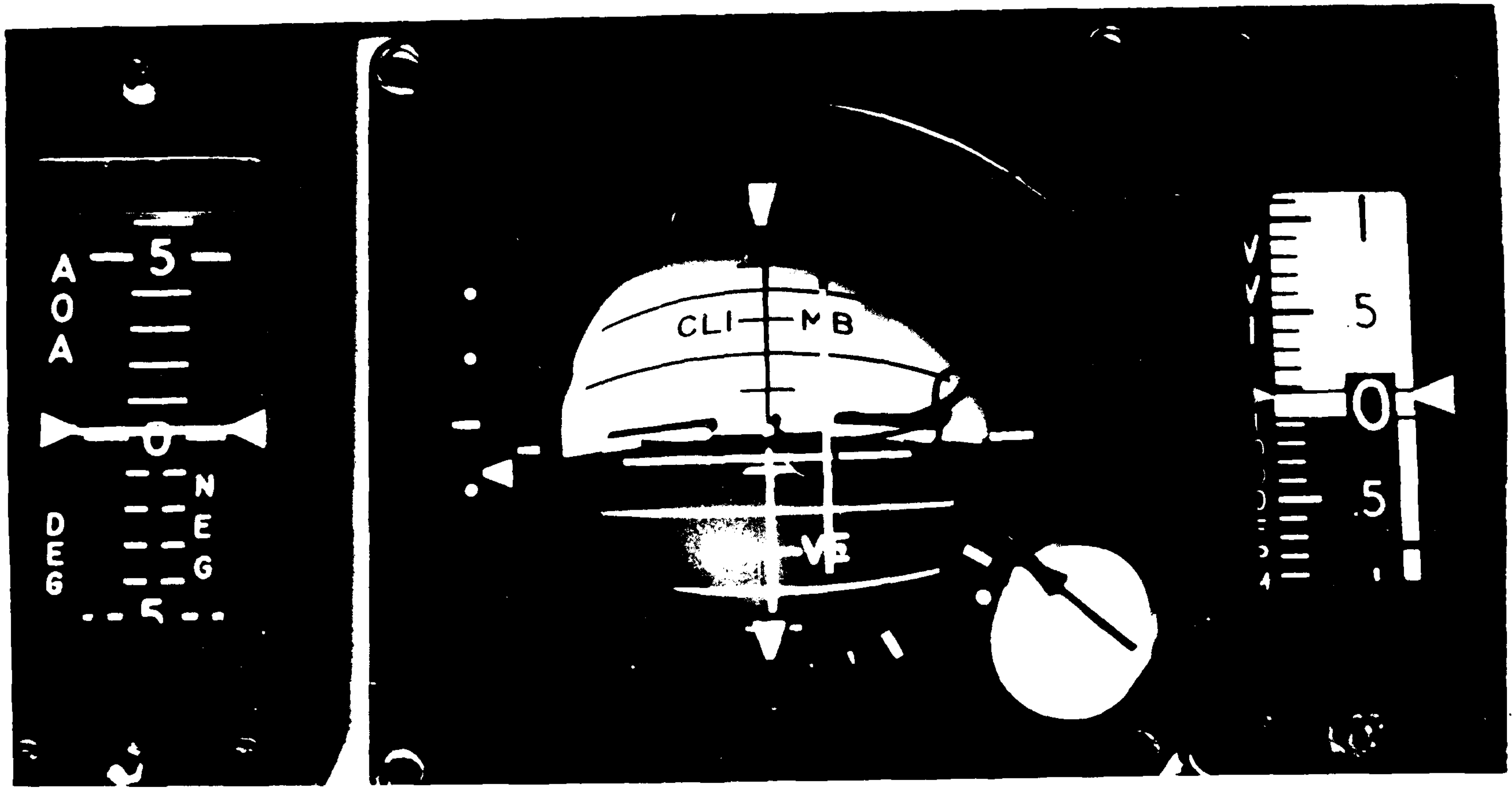

Figure 7. Configuration 3: Attitude Indicator with Flight Director Steering and Improved Tape Vertical Velocity Indicator.

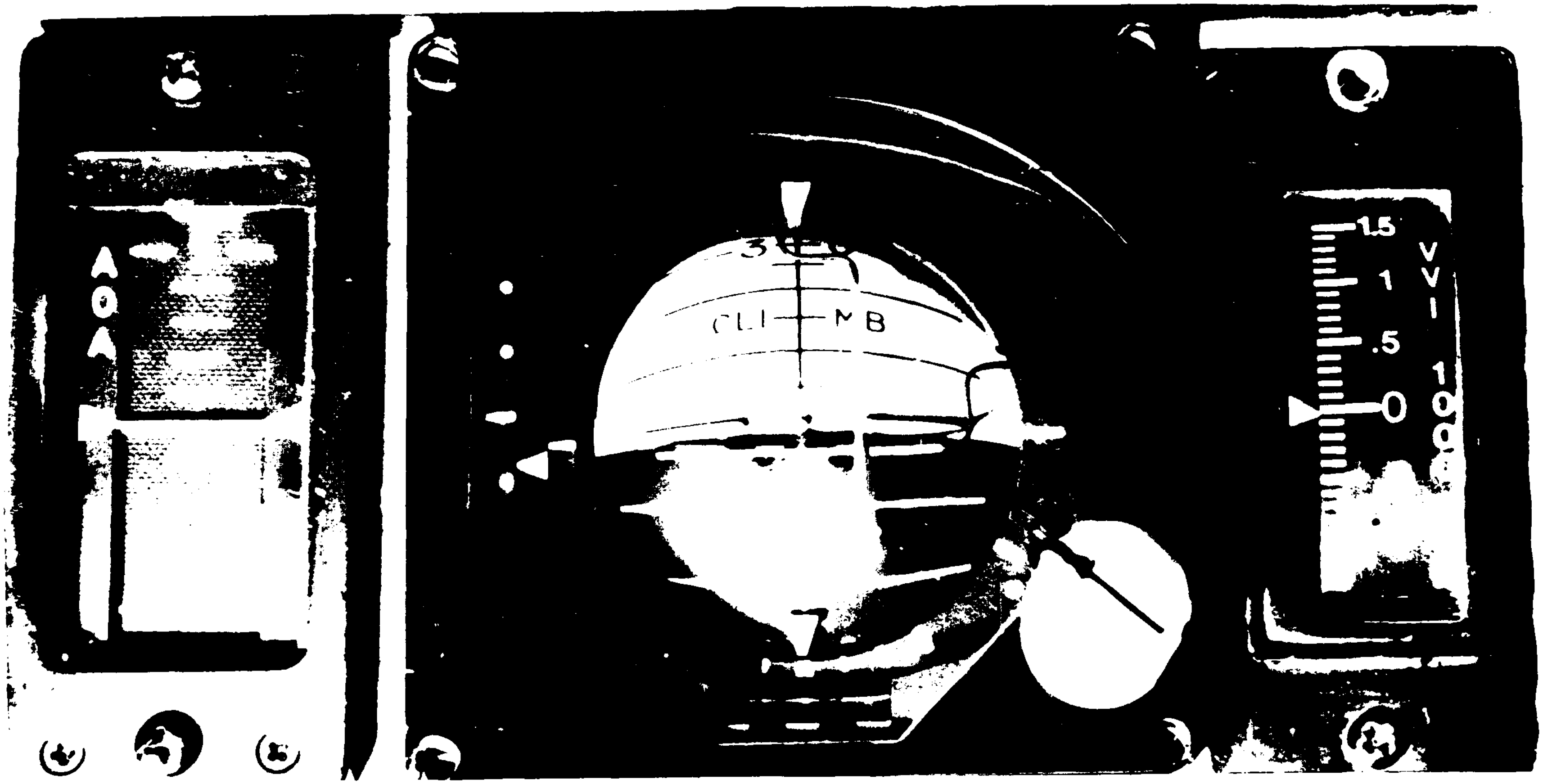

Figure 8. Configuration 4: Attitude Indicator with Flight Director Steering and Moving Pointer Vertical Velocity Indicator.

an experimental moving pointer VVI (MP) (shown in Figure 8). The following paragraphs present a more detailed description of Configurations 1 and 2 along with rationale used in arriving at modifications expected to improve system performance. The HUD was not presented to the pilot in any of the evaluation configurations.

A. Configuration 1: Block 40 Baseline. The baseline head-down displays, shown in Figure 5, were in the ILS/TCN configuration used to fly an ILS approach or to monitor the ILS while flying a radar controlled (GCA) approach. The RD is a unique configuration; departing from conventional display concepts by presenting raw ILS localizer and glideslope deviation on what are normally pitch and bank steering bars.

Vertical velocity information in this baseline instrument set is displayed on a moving tape against a fixed pointer (the IT). In order to use the display, pilots must read or interpret values shown at the pointer as opposed to interpreting pointer position on conventional displays. A second potentially misleading feature of this display is the fact that tape movement during climb and descent maneuvers is opposite that of a moving pointer on other displays.

B. Configuration 4: All-Modified Display Configuration

(1.) Attitude Director Indicator with Flight Director (FD). In the modified head-down set the FD was mechanized in a conventional manner using Flight Director inputs from the HUD to drive the pitch and bank steering bars although the HUD itself was not displayed to the pilot in this study.

ILS raw data displays on the RD and Horizontal Situation Indicator HSI are selected using the Instrument Mode Selector on the center pedestal. The steering (FD) function was selected through the Instrument Control Panel (ICP) and the DED. For this evaluation, command steering mode selection defaulted to ON; the bars could be removed (for raw data ILS or for monitoring ILS information while flying a GCA) by de-selecting the comp steer mode on the ICP/DED.

The FD had a grey/black color scheme for the sky/ground

presentation, an example of more conventional attitude sphere coloring, as opposed to the blue/brown colors used in the F-16 attitude indicator. While this should have had no effect on the results of the evaluation, pilots were asked to rate their preference with regard to the color scheme on subjective questionnaires.

(2.) Vertical Velocity Indicator (VVI). A locally modified VVI was used to show this performance parameter in a conventional manner. The display shows a range of + 1500 ft. per minute on a stationary scale with a moving pointer. This display was not intended to be the final solution to the F-16 VVI problem; rather, it allowed pilots to look at one option that could, if the format was desired, be developed into a viable flight instrument. Due to the limited capabilities of the local manufacturing, the MP had no interior lighting. Exterior lighting was supplied by the Utility Light.

Computer Complex. The computer complex at CSDF consists of five Gould Series 32/7780, one Gould Concept 32/8780 mainframe computers, two PDP11/34 and three PDP11/35 computers, and two Silicon Graphics Iris 2400 graphics stations.

Visual System. The out-the-window visual scene was provided using a computer-generated Night Visual System (NVS) that became visible as the aircraft descended below 200 ft.

Experimenter's Console. The experimenter's console includes a complete intercom system for four experimenter/observers, together with communication to and from the pilot inside the simulator. The console's displays duplicate the pilot's visual, HUD, and MFDs, and have a representation of an Air Traffic Controller's Ground Control radar screen to enable the experimenter to observe and monitor the pilot's performance. The console controls enable the experimenter to start, stop and reset the simulation. An attached computer terminal was used to access the mainframe computers to input the mission number, subject number, segment number, and to start and stop data

collection.

Simulator Workload Measurement System (SWMS). SWMS is a hardware and software system designed to collect and analyze measures of mental workload in an aircraft simulation environment. For the p :poses of this evaluation, only the Eyeblink Analysis of the Electroculogram (EOG) was used in an attempt to measure mental workload.

The SWMS eyeblink analysis system consists of a Digital Equipment Corporation (DEC) LSI 11/23 computer, dual floppy disk drives, a 16-channel A/D converter, and a DEC VT125 graphics terminal.

SUBJECTS

Seven pilots took part in the study. Six were rated USAF pilots, one was a rated Royal Air Force pilot. Of the USAF pilots, five flew the F-16 and one flew the F-15. Table 1 shows their qualifications and flying experience. Their flying experience ranged from 2000 to 3610 flight hours, with a mean flight experience of 2775 hours. Actual F-16 experience ranged from 0 to 1200 flight hours, with a mean flight experience of 525.7 hours and a standard deviation of 506.1 hours.

Table 1. Subject pilot flying experience.

NUMBER	F-16 HRS	TRAINER HRS	OTHER AIRCRAFT	TOTAL
1	80	500	2200	2780
2	-	770	1580	2350
3	-	70	2500	2570
4	600	200	1200	2000
5	1050	185	1100	2335
6	1200	210	2200	3610
7	750	1300	725	2775
AVERAGE:	736	462	1644	2631

MISSIONS

All training and data collection flights in the evaluation were flown to an ILS approach and to touch and go (see Figure 9 and the training viewgraph in appendix D). The profile was flown as it would be with Air Traffic Control (experimenter) providing the vector to a 45-degree localizer intercept heading and landing clearance. The simulated weather environment included a 200-ft ceiling with unlimited visibility below the ceiling; winds were 225 degrees at 10 kts (a 90-degree crosswind) reducing linearly to calm at touchdown. Evaluation pilots made the localizer intercept using ILS guidance and completed each approach using one of the four display configurations specified in the Display Configurations section.

TEST PROCEDURES

When the pilots arrived to participate in the study, they each filled out a personal data questionnaire (Appendix A). They were then given a short, general briefing on the Crew Station Design Facility. This was followed by a detailed briefing concerning the study in which they participated. The pilots were then taken to the simulator area where they flew orientation approaches on each of the four configurations used in the study. Each pilot then flew two sets of four missions for data, each mission consisting of five approaches, for a total of 40 approaches. During the first four missions, the pilots flew an arrangement of each of the four configurations and in the second four missions, flew the same arrangement. No two pilots flew the same arrangement of configurations. The experimenter recorded pilot comments during all of the data runs. At the conclusion of the evaluation, each pilot was debriefed and filled out a final comprehensive questionnaire (see Appendix B).

Eyeblink measures were taken on each pilot's sixth through tenth mission. The SWMS system was fitted to each pilot by attaching one electrode above, and one below, the right eye on the skin of the pilot using electrode attachment collars and an electrolyte gel. A third

ground electrode was emplaced behind the pilots right ear on his neck. The electrodes were then left in place as long as practical (during rest periods) or replaced before the pilot flew again.

Each mission consisted of five approaches separated only by the time that it took the experimenters to reset the instrumentation and simulation. A detailed description of the simulation follows:

Test Approach:

Start:
a. Initial position: 51,894 ft. from approach end of runway at 25.1 degrees left of centerline.
b. Initial approach altitude: 1500 ft.
c. Initial airspeed: 200 KCAS.
d. Initial heading: 225 degrees.
e. Landing gear: up position.
f. Speedbrake: closed.
g. Final approach and runway heading: 315 degrees.
h. runway altitude: 16.0 ft.

Pattern:
a. Experimenter 1 insures that pilot is ready and begins the simulation with: "You are flying."
b. 45-degree turn to intercept final initiated by Air Traffic Control (ATC) (Experimenter 1): "Falcon XX, turn right heading 270, dogleg to final approach," at approximately 35 seconds into the approach. Once a heading within 3 degrees of 270 has been attained, ATC radios: "On a heading of 270 you will intercept the localizer in (some fraction, depending on actual aircraft position) mile.
c. 45-degree turn to intercept final (Pilot initiated).
d. Intercept glideslope and fly approach to touch-and-go. (Experimenter 1 states, "Falcon XX, we have you intercepting glideslope, (some number, depending on actual aircraft position) miles from touchdown, recheck gear, cleared touch-and-go," at the time that the aircraft actually intercepts the glideslope.
e. After touch-and-go, the simulator was reset and

readied for the next approach (this procedure usually took less than a minute), or, after five approaches, for the next pilot.

Experimenter duties:

1. Duties of Experimenter 1

   a. Brief.
   b. Make sure simulator and Evaluation pilot are set for. each run.
   c. Act as approach controller for vectors to ILS.
   d. Observations during approach.
   e. Debrief.

2. Duties of Experimenter 2

   a. Watch data collection.
   b. Note Evaluation pilot's comments.
   c. Note Experimenter 1's comments.
   d. Administer questionnaires.

BRIEFING/DEBRIEFING

Pilots were briefed prior to each series of data runs (five per session) on setup procedures, sequence of runs, and communications/coordination requirements. Following each data collection segment, the pilots were debriefed with special emphasis on any control/display problems or weaknesses encountered and on any display features that enhanced precision or reduced pilot workload.

TRAINING

All pilots participating in the evaluation received the same training prior to the start of data collection. This training

included details on display mechanization, Flight Director mechanization/operation, approach procedures and recommended flight techniques for each display/approach configuration. Following ground school, each pilot flew a series of approaches consisting of one of each configuration to be used in the evaluation. These training runs were flown in unlimited visibility, simulated night conditions. All experimental runs were flown in simulated night weather conditions (200 ft. ceiling, 0.5 mile visibility). Training handouts are provided in Appendix C.

DESIGN

This experiment was designed to compare the relative virtues of four aircraft instruments, two attitude indicators and two vertical velocity indicators, in their roles supporting an ILS approach. Also of interest to the evaluation was the effect of training on performance. Therefore, a third independent variable, Replication (two levels), was included in the design.

Three classifications of data were collected: Objective performance data, physiological (eyeblink) workload data, and subjective questionnaire data.

Objective data. Aircraft performance data were recorded over a range of 2.0 to 1.5 Nm from the modelled glideslope transmitter. The mean of the absolute values and the standard deviation from the mean were collected on nine data parameters (shown in Table 2). Since readings were made every 200 milliseconds (at a rate of 5 Hz), the data were averaged over the 0.5 Nm range. A diagram of a normal ILS touch and go is shown in Figure 9, and diagram of the simulated ILS approach is shown in Figure 10.

The use of deviation (whether absolute or standard deviation) as an indicator of the level of workload has been previously validated, both in the basic (Fisk and Schneider, 1983) and the applied (Ranney and Gawron, 1986) arenas. It appears that when subjects need to

ILS *(Typical)*

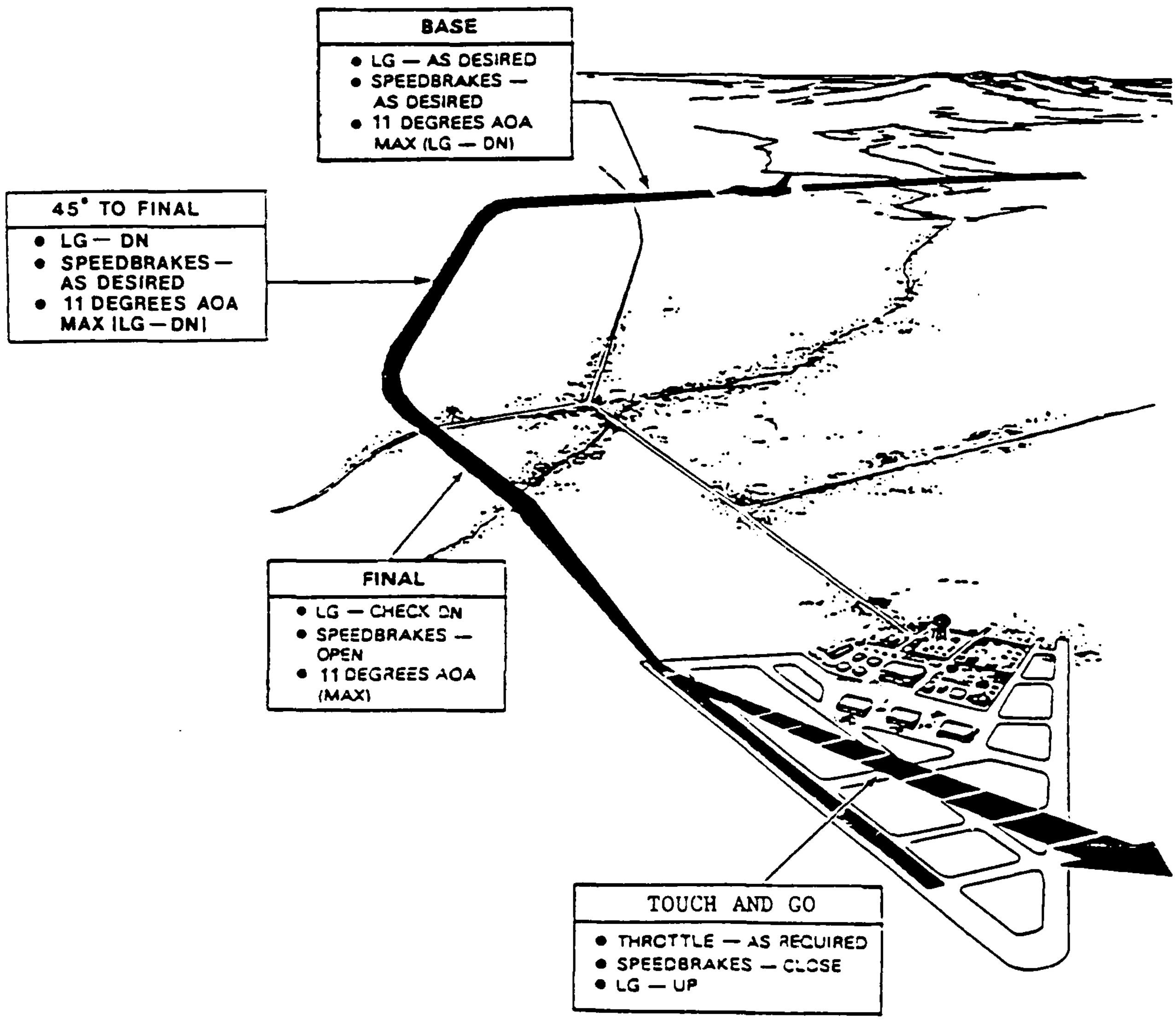

Figure 9. Normal ILS approach.

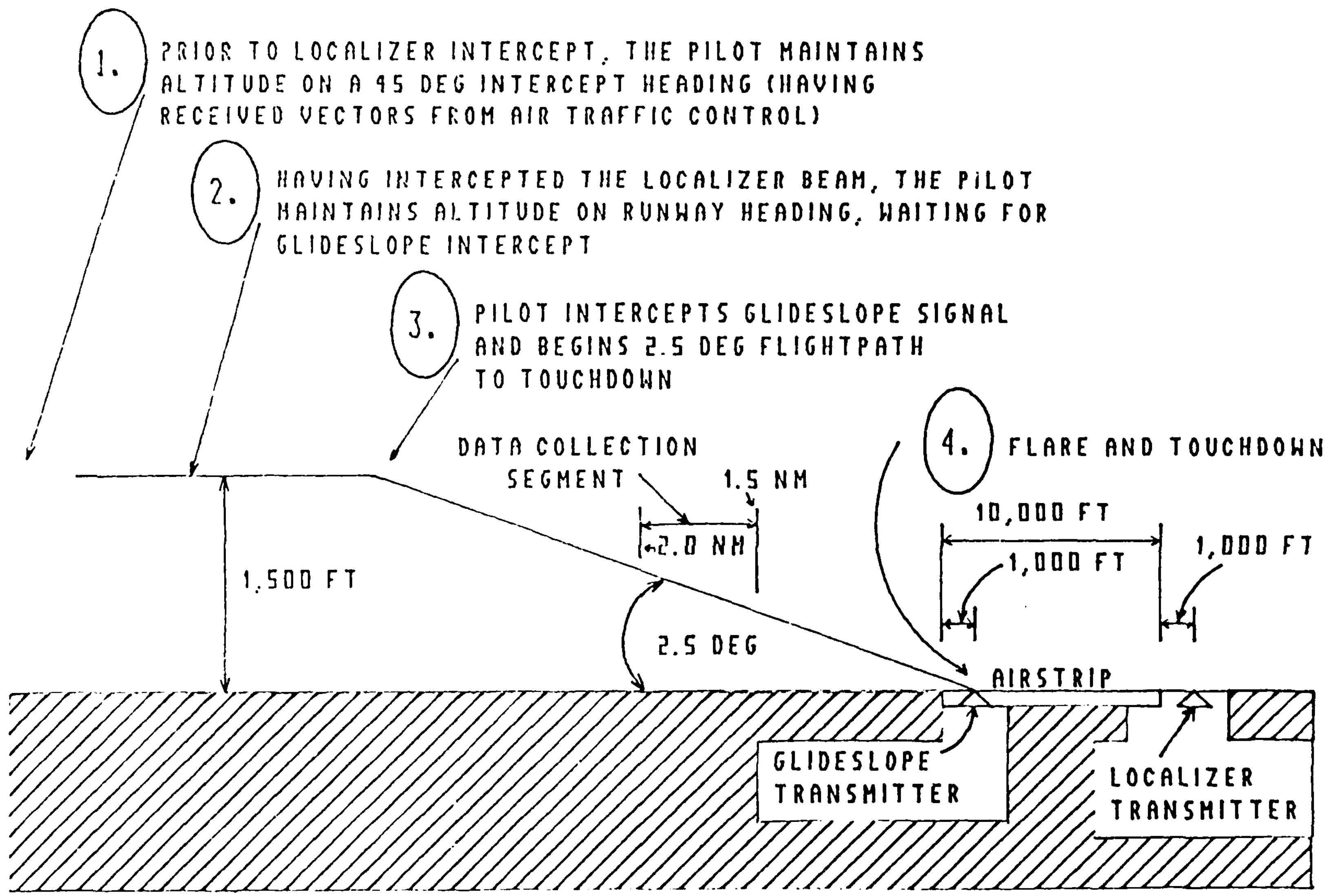

Figure 10. Simulated ILS approach.

allocate more attention in order to perform a specific task (for the present evaluation, flying an approach in the F-16), a facet of the human information processing activity tends to manifest itself through poorer performance. For this evaluation, this performance decrement should have been demonstrated through the pilot's inability to consistently track the desired ILS approach.

Table 2. Objective data parameters.

VARIABLE	UNITS	EXPLANATION
localizer deviation	degrees	number of degrees horizontal deviation from centerline of runway
glideslope deviation	degrees	number of degrees vertical deviation from the glide path
airspeed deviation	knots	difference between desired and actual airspeed
angle of attack deviation	degrees	difference between desired and actual angle of attack
pitch rate	degrees/second	rate of change of pitch angle
roll rate	degrees/second	rate of change of roll angle
pitch attitude	degrees	actual aircraft pitch
roll attitude	degrees	actual aircraft roll
flight path	degrees	number of vertical degrees from the horizontal

A description of each of the nine objective performance data parameters follows with a discussion of why these parameters were chosen.

1. Localizer Deviation (LOCDEV) - The number of degrees of horizontal deviation from the runway centerline was collected to

determine the level of horizontal situation control that a given instrument could provide. The higher the absolute average of LOCDEV, the worse the performance of the pilot in maintaining runway centerline; the higher the standard deviation of LOCDEV, the more workload expended in maintaining runway centerline due to undershooting, overshooting, and corrections. A LOCDEV of zero, for any given time, would indicate that the aircraft was on runway centerline. Any other value would indicate some distance from centerline, dependent upon the distance from the modelled localizer transmitter by the equation:

$$R_{ld}\tan(LD) = X$$

R_{ld} = range from the localizer transmitter in feet
LD = localizer deviation in degrees
X = horizontal distance from runway centerline in feet

For the purposes of this study, the localizer transmitter was modelled as being on the departure end of the 10,000 ft runway, and on runway centerline.

2. Glideslope Deviation (GSDEV) - The number of degrees of vertical deviation from the glide path (2.5 degrees) was collected to determine the level of vertical situation control that a given instrument could provide. The higher the absolute average of GSDEV, the worse the performance of the pilot in maintaining glidepath; the higher the standard deviation of GSDEV, the more workload expended in maintaining glidepath due to undershooting, overshooting, and corrections. A GSDEV of zero, for any given time, would indicate that the aircraft was on glideslope. Any other value would indicate some distance from centerline, dependent upon the distance from the modelled glideslope transmitter by the equation:

$$[R_{gd}\tan(GD)]-[(R_{gd})(0.0437)] = Y$$

R_{gd} = range from glideslope transmitter in feet
GD = glideslope deviation in degrees
Y = distance from glidepath in feet

For the purposes of this study, the glideslope transmitter was modelled as being 1,000 ft from the approach end of the runway and on runway centerline.

3. Airspeed Deviation (A/SDEV) - The number of knots difference, at a given time, between actual aircraft airspeed and desired approach airspeed (141.5 kts).

4. Angle Of Attack Deviation (AOADEV) - The number of degrees difference, at a given time, between actual aircraft angle of attack and the desired angle of attack (11.0 deg).

5. Pitch Rate (PR) - The rate of change, at a given time, of aircraft pitch in degrees per second.

6. Roll Rate (RR) - The rate of change of aircraft roll angle, at a given time, in degrees per second.

7. Roll Attitude (RA) - The aircraft roll angle at a given time in degrees.

8. Pitch Attitude (PA) - The aircraft pitch at a given time in degrees.

9. Flight Path (FP) - The actual flight path of the aircraft at a given time.

The statistics collected were the absolute mean and the standard deviation. These statistics on the the data parameters were averaged over the 0.5 Nm range discussed earlier.

Each data parameter was chosen for its ability to indicate differences in performance and workload. LOCDEV, GSDEV, A/SDEV, AOADEV, PA, RA, and FP were chosen to indicate adherence to the published approach as set forth in the previous discussion of the data parameters. PR and RR were chosen as workload measures, a higher rate indicating a higher workload.

<u>Physiological Measures</u>. Each pilot's eye blink data were collected in an attempt to assess the level of mental workload associated with the different instrument configurations. The theory behind the eye blink workload assessment technique assumes that human visual attention is directly related to the level of mental load induced by a specific task. When mental load is increased, the frequency, amplitude, and duration of eye blinking seems to decrease. The use of eye blink measure as index of pilot workload has been previously validated both in basic (Stern et al., 1984) applied (Purvis and Skelly, 1986) settings.

The data parameters were recorded continuously in ten-second segments throughout the approach at a rate of 250 Hz. The parameters recorded were: blink amplitude, half closure duration, number of blinks, 50% descent, and closure duration.

<u>Subjective Questionnaires</u>. Post test questionnaires were used to address particular topics relevent to the flight instruments used in this evaluation. A copy of the questionnaire, showing the pilots' responses, can be found in Appendix B. Each pilot filled out a questionnaire after all of the test missions had been flown. Questions in the questionnaire covered topics including: Pilot preferences of one display over another (these allowed for reasons to be stated), significant problems with the displays, sky/ground coloring of the attitude sphere, steering bar size and contrast, location of flight instruments used on ILS approaches, and the CSDF simulator performance.

RESULTS

OBJECTIVE DATA

Since the critical factor relating instrument flying to aircraft control is the amount of deviation associated with different parameters, it was decided that the average of the absolute values and the standard deviation from the mean would be the two relevant indicators of flying performance. Each of these two measures were computed for nine different data parameters: Localizer deviation, glideslope deviation, airspeed deviation, angle of attack (AOA) deviation, pitch rate, roll rate, pitch attitude, roll attitude, and flight path (these data parameters are fully described in the Design section). All of the data parameters were analyzed in a 2 x 2 x 2 repeated measures Analysis of Variance (ANOVA), using the Statistical Analysis System (SAS, 1985); two AI instruments (FD versus RD), two VVI instruments (MP versus IT), and two replications. Responses from two test runs were mistakenly overwritten by the data collection computer system, resulting in the loss of some of the data. The General Linear Model (GLM) procedure (SAS, 1985) was used to compensate for missing data throughout the analyses. Regardless of the number of missing data, and through the concept of estimability, GLM can provide tests of hypotheses for the effects of a linear model by computing the Sum of Squares (SS) associated with each hypothesis tested. GLM can produce the form of all estimable functions.

The environment associated with the present simulation tended not to restrict the pilots' sole focus on the AI and/or the VVI, but rather to incorporate the instruments in a more complete mission scenario. This in turn decreased the level of experimenter control over the pilots' decisions and actions during the task performance. In order not to overlook any significant effects between the different instruments during the evaluation, it seemed appropriate to assume a liberal stand in accepting the alternative hypothesis, by selecting confidence level (p value) of less than, or equal to 0.10.

Average of the Absolute Values. The average of the absolute values is an indication of the average of the total deviation from the mean, regardless of the sign of the deviation (+ right, - left, + up, - down, etc.).

The pilots' averages of the absolute values indicated an advantage for the FD over the RD, in three of the nine data parameters. The AI means for each data parameter are illustrated in Table 3. The main effect of AI was found statistically significant for: Pitch rate, $F(1,6) = 10.71$, $p = 0.10$; roll rate, $F(1,6) = 49.49$, $p = .10$; and roll attitude, $F(1,6) = 41.12$, $p = .10$. None of the other six data parameters showed any statistically significant differences between the FD and the RD.

In examining pilots' performance between the two VVIs (shown in Table 4), the absolute value means did not seem to differ when the pilots were flying the F-16 with the MP versus flying the F-16 with the IT. No statistically significant results were obtained from the analysis of variance for the main effect of VVI for any of the nine data parameters.

As shown in Table 5, pilots' performance did not seem to improve with practice either. Statistically non-significant results were found in the analysis of the main effect of Replications for all of the data parameters.

Similar non-significant results were gathered from the two-way interactions (AI versus VVI; AI versus Replications; and VVI versus replications), and the three-way interaction (AI versus VVI versus replications).

Standard Deviation. The standard deviation, which is the square root of the average of the squared deviations from the mean (also known as the square root of the variance), is an index of variability in the original measurment units. For most of the data parameters being analyzed, the measure is describing the average deviation of the average deviation from the treatment mean.

The pilots' standard deviations were in agreement with the

Table 3. Pilots' means of the absolute values for the Flight Director and the Raw Data.

	Raw Data	Flight Director
Localizer Deviation	0.207	0.210
Glideslope Deviation	0.187	0.192
Airspeed Deviation	10.326	9.134
Angle of Attack Deviation	2.028	1.983
Pitch Rate	0.697	0.485 *
Roll Rate	2.090	1.094 *
Pitch Attitude	7.423	7.075
Roll Attitude	3.166	1.614 *
Flight Path	3.484	3.661

* Means are statistically different at 0.10 level.

Table 4. Pilots' means of the absolute values for the Improved Tape and the Moving Pointer.

	Improved Tape	Moving Pointer
Localizer Deviation	0.207	0.210
Glideslope Deviation	0.172	0.208
Airspeed Deviation	10.178	9.247
Angle of Attack Deviation	2.068	1.939
Pitch Rate	0.617	0.564
Roll Rate	1.633	1.548
Pitch Attitude	7.167	7.337
Roll Attitude	2.319	2.466
Flight Path	3.523	3.626

Note: None of the means are statistically different at 0.10 level.

Table 5. Pilots' means of the absolute values for the first and the second Replications.

	Replication One	Replication Two
Localizer Deviation	0.222	0.196
Glideslope Deviation	0.184	0.194
Airspeed Deviation	9.641	9.813
Angle of Attack Deviation	2.020	1.993
Pitch Rate	0.633	0.553
Roll Rate	1.688	1.503
Pitch Attitude	7.268	7.232
Roll Attitude	2.381	2.398
Flight Path	3.557	3.587

Note: None of the means are statistically different at 0.10 level.

results obtained by the pilots' means of the absolute values. Pilots' standard deviations were significantly smaller when the aircraft was flown with the FD as opposed to when it was flown with the RD. The AI mean standard deviations are shown in Table 6. The main effect of AI was found to be statistically significant in seven of the nine data parameters: Localizer deviation, $F(1,6) = 5.20$, $p = .10$; AOA, $F(1,6) = 5.90$, $p = 0.10$; pitch rate, $F(1,6) = 13.98$, $p = 0.10$; roll rate, $F(1,6) = 45.17$, $p = 0.10$; pitch attitude, $F(1,6) = 6.15$, $p = 0.10$; roll attitude, $F(1,6) = 50.17$, $p = 0.10$; and flight path, $F(1,6) = 4.05$, $p = 0.10$. While the analysis of variance of the main effect of AI for glideslope deviation and speed were not statistically significant, an examination of the means in Table 6 indicated that the values are heading in the same direction as the other seven data parameters, i.e. better performance with the FD.

The analysis of the main effect of VVI as a function of the

standard deviation, resulted in statistically significant differences for only one data parameter (the means are presented in Table 7). Pilots' standard deviations for speed seemed to be smaller when the aircraft was equipped with the IT, $F(1,6) = 4.10$, $p = 0.10$. The average speed standard deviations, corresponding respectively with the IT and MP, were 2.251 and 1.890 knots.

As in the analysis of the average of the absolute values, Replications did not seem to have an effect on pilots' standard deviation performance. The main effect of Replications was not found to be statistically significant with any of the nine data parameters. The means of the standard deviations for Replications are shown in Table 8.

Table 6. Pilots' means of the standard deviation for the Flight Director and the Raw Data.

	Raw Data	Flight Director
Localizer Deviation	0.073	0.053 *
Glideslope Deviation	0.075	0.064
Airspeed Deviation	2.134	1.993
Angle of Attack Deviation	0.794	0.629 *
Pitch Rate	0.936	0.651 *
Roll Rate	2.967	1.553 *
Pitch Attitude	1.055	0.835 *
Roll Attitude	3.370	1.550 *
Flight Path	1.028	0.838 *

* Means are statistically different at 0.10 level.

Table 7. Pilots' means of the standard deviation the Improved Tape and the Moving Pointer.

	Improved Tape	Moving Pointer
Localizer Deviation	0.061	0.065
Glideslope Deviation	0.063	0.077
Airspeed Deviation	1.890	2.251 *
Angle of Attack Deviation	0.721	0.702
Pitch Rate	0.821	0.763
Roll Rate	2.305	2.211
Pitch Attitude	0.961	0.927
Roll Attitude	2.382	2.544
Flight Path	0.925	0.942

* Means are statistically different at 0.10 level.

Table 8. Pilots' means of the standard deviation the first and the second Replications.

	Replication One	Replication Two
Localizer Deviation	0.065	0.061
Glideslope Deviation	0.075	0.065
Airspeed Deviation	2.003	2.121
Angle of Attack Deviation	0.735	0.690
Pitch Rate	0.850	0.741
Roll Rate	2.426	2.106
Pitch Attitude	1.023	0.872
Roll Attitude	2.495	2.427
Flight Path	0.930	0.936

Note: None of the means are statistically different at 0.10 level.

Interesting results came out of the analysis of the two-way interaction between AI and VVI. The Analyses of Variance on five of the nine data parameters resulted in statistically significant interactions. These were: Localizer deviation, $F(1,6) = 8.19$, $p = 0.10$; glideslope deviation, $F(1,6) = 12.05$, $p = 0.10$; angle of attack deviation, $F(1,6) = 40.48$, $p = 0.10$; pitch attitude, $F(1,6) = 6.89$, $p = 0.10$; and flight path, $F(1,6) = 14.30$, $p = 0.10$. A further decomposition of the significant data by each of the two AIs is described in the following section. The interaction data are shown in Figure 11. An examination of Graphs 1a through 1d in Figure 11, representing glideslope deviation, AOA deviation, pitch attitude, and flight path, suggest that there was an overall performance benefit when the aircraft was equipped with an FD (this was also demonstrated by the significant main effect of AI). Furthermore, it can be seen

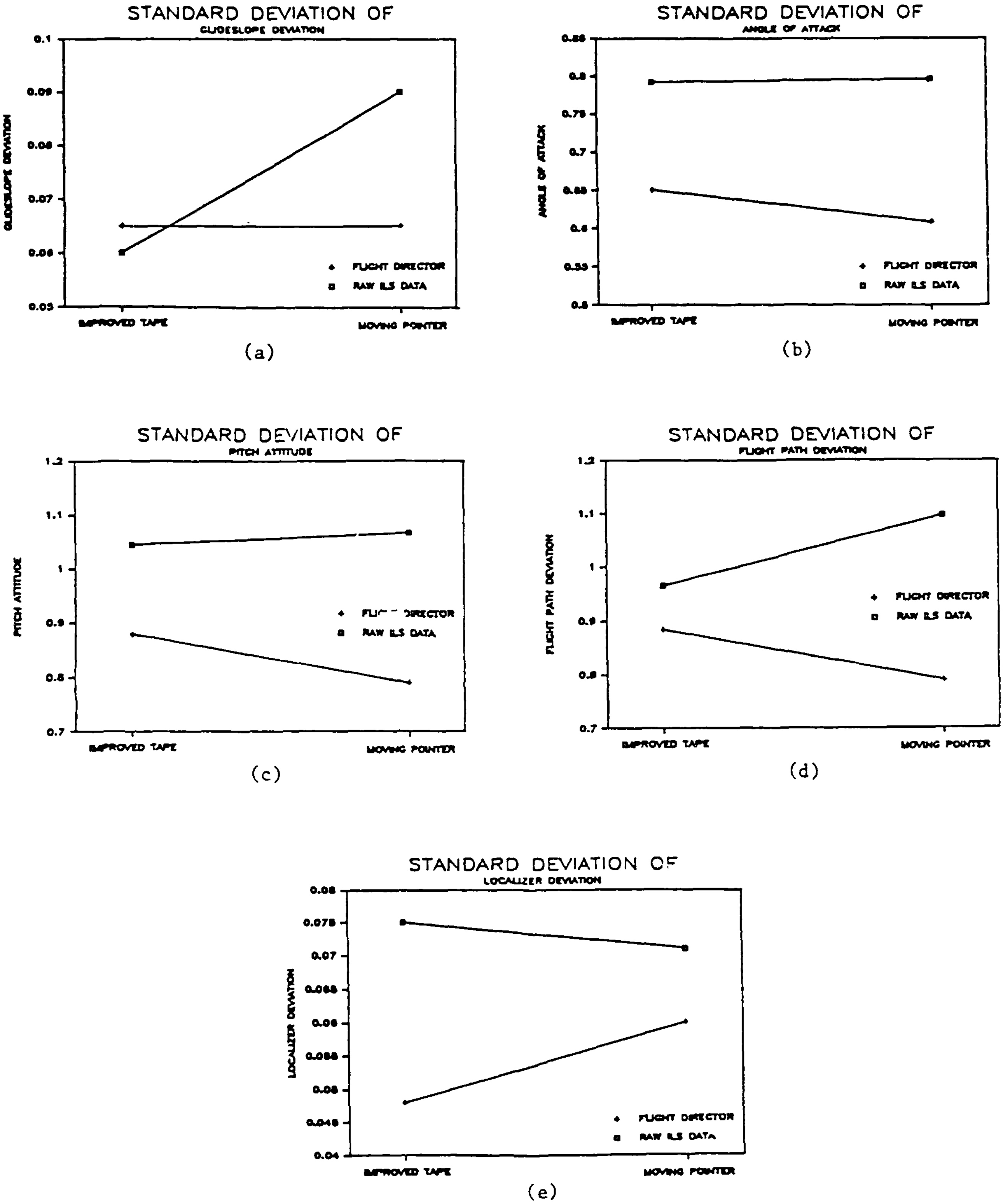

Figure 11. Five Data Parameters as a Function of AI x VVI Using Standard Deviation.

from examining the graphs that the FD advantage increased when it was coupled with the MP as opposed to the IT VVI. Performance either did not change, or became worse, when the aircraft's cockpit configuration was changed from that of an RD/MP to an RD/IT.

The localizer deviation data do not confirm the previous interactions. An examination of Figure 11 (e) suggest that while an advantage of FD over RD was apparent when the FD was coupled with the IT, this difference seems to disappear when either of the two AIs were coupled with the MP VVI. These results should not cause any major concern regarding the validity of the previous interpretations of the interaction data, because localizer deviation is based on horizontal movements rather than vertical ones, and therefore should not have been influenced by information displayed on the VVI.

In comparing the results presented by the two measures (absolute values and standard deviations), it seems that for the purpose of this evaluation, standard deviation was more sensitive in predicting pilot workload than was the mean of the absolute values.

PHYSIOLOGICAL DATA

Pilots' eye blink data were collected in an attempt to assess the level of mental workload associated with the different instrument configurations. Two AIs (FD versus RD) and two VVIs (MP versus IT) were evaluated as a function of five different eye blink parameters in five different 2 x 2 repeated measures Analyses of variance. The five different eye blink parameters were: (1) Blink amplitude, (2) half closure duration, (3) number of blinks, (4) 50% descent, and (5) closure duration. The AI means are shown in Table 9, while the VVI means are shown in Table 10.

Table 9. Pilots' means of the eye blink data parameters for the Flight Director and the Raw Data.

	Raw Data	Flight Director
Blink Amplitude (A-D Units)	164.367	200.12
Half Closure Duration (Seconds)	0.13	0.12
Number of Blinks (Frequency)	2.15	2.17
50% Descent (Seconds)	0.05	0.05
Closure Duration (Seconds)	0.10	0.09

Note: None of the means were statistically different at 0.10 level.

Table 10. Pilots' means of the eye blink data parameters for the Improved Tape and the Moving Pointer.

	Improved Tape	Moving Pointer
Blink Amplitude (A-D Units)	195.47	167.78
Half Closure Duration (Seconds)	0.13	0.12
Number of Blinks (Frequency)	2.36	1.99
50% Descent (Seconds)	0.05	0.05
Closure Duration (Seconds)	0.09	0.09

Note: None of the means were statistically different at 0.10 level.

None of the physiological eye blink measures appeared to be sensitive enough to detect any significant effects between the different instrument configurations. The Analyses of Variance, for all five parameters, failed to result in statistically significant two-way interactions or significant main effects for either AI or VVI, at the 0.10 confidence level.

QUESTIONNAIRE DATA

At the completion of the experiment, all seven subjects responded to a questionnaire which was designed to address the particular topics covered in the TAC message (discussed in the introduction). The following paragraphs briefly summarize the pilots' responses and comments from the questionnaire. Because of the small sample size, no formal statistical analyses were performed on the questionnaire data. A complete summary of the ratings are shown in Appendix B.

Vertical Velocity Displays. Six of the seven pilots preferred the locally manufactured MP display over the modified F-16 Moving Tape, although four of the subjects stated that they did have some problems when using the MP, citing scaling, pointer sensitivity, instrument size, and lighting (the moving pointer had no interior lighting). The subjects (five out of seven) also reported some problems associated with the IT, such as scaling, pointer sensitivity, and direction of movement.

Attitude Indicator. Six out of seven pilots considered the AI with FD steering to yield a more accurate approach and to induce less workload than the RD with raw ILS data.

Display Coloring.

1. Sky/Ground Presentation. The colors used on the F-16 AIs differed from blue/brown (sky/ground) for the RD, to gray/black (sky/ground) for the FD. When pilots were asked to indicate their preferences for

the AI colors, decisions were split. Four out of the seven selected the gray/black over the blue/brown color scheme.

2. Pitch and Bank Steering Bar Contrast. The steering bars on the FD were an off-white color, which was similar to the coloring of the miniature aircraft. Written comments made by the pilots, suggested that the lack of contrast between the steering bars and the miniature aircraft made it difficult at times to perceive small pitch steering errors.

3. Pitch and Bank Steering Bar Size. The steering bars on the FD were thinner than the ones implemented on the F-16 RD. Five of the seven pilots indicated that they preferred the FD's thinner steering bars. Two of the subjects further added that they would prefer the steering bars even thinner that the ones used on the FD.

<u>Flight Instrument Positions</u>. Five of the pilots rated the position of the flight instruments in the F-16 to be too low for precision flight in a radar vector pattern and ILS final approach. Six pilots also rated the location of the flight instruments to be too low for precision flight, in the transition to visual for landing from an ILS approach. One pilot considered the position of the instruments to be "about right" for precision flight in a radar vector pattern and ILS approach, as well as in the transition to visual for landing from an ILS approach.

DISCUSSION

The results of the present evaluation primarily suggested that the use of an FD-equipped AI in the F-16 C/D will increase the precision of ILS approaches and decrease the level of workload imposed on the pilot. This mechanization will, in turn, provide the pilot with a safer and more secure landing process.

Although the objective evaluation of the two VVIs did not indicate a consistent advantage of one instrument over the other, the pilots' subjective evaluation favored the Moving Pointer over the Improved Tape.

ATTITUDE INDICATOR

While the objective and subjective data favored the FD AI over the RD AI, the physiological data were not sensitive to the effect.

Of the nine data parameters examined throughout the objective statistical analyses for this ILS approach, Pitch Rate and Roll Rate resulted in the most responsive workload indices. The two performance measures, absolute values and standard deviations, exhibited statistically significant advantages for the FD over the RD when tested on Pitch Rate and Roll Rate. The higher changes in Pitch Rate and Roll Rate, demonstrated by flying the RD equipped F-16, were indicative of a higher workload condition and less precision.

The subjective data further supported the objective data, in that pilots consistently rated the FD more favorably than the RD AI.

VERTICAL VELOCITY INDICATOR

Only the subjective questionnaire data demonstrated any differences between the Vertical Velocity Indicators. The pilots were in favor of the Moving pointer over the IT VVI. Neither the

objective, nor the physiological data yielded any significant differences between the two instruments.

The subjective data showed that, despite some problems cited with the scaling, pointer sensitivity, instrument size, and lighting (the utility light was used to illuminate the MP, as it had no interior lighting), the pilots preferred the MP over the IT VVI.

One possible explanation to the insensitivity of the objective and physiological measures in detecting differences between the two Vertical Velocity Indicators, may be reflected by the nature of the mission flown by the pilots. The mission may not have been directly geared into requiring the pilots to substantially rely on the data provided by the VVI.

INTERACTION BETWEEN AI AND VVI

The objective data demonstrated a significant AI by VVI interaction. As in the main effect analyses, the physiological data were not sensitive to the interactions, while the subjective data did not consider the AI/VVI interaction as part of the evaluation.

The results of the interaction of the objective data suggested that the pilots experienced a smaller amount of workload when the F-16 was configured with the FD AI and the MP VVI, in comparison with the other three configurations (FD/IT; RD/MP; RD/IT). The significant effect was demonstrated by the analysis of the standard deviations on AI by VVI.

CONCLUSION

In conclusion, it is our technical opinion that the implementation of an FD AI would enhance pilot performance in an ILS approach. Furthermore, of the two VVIs evaluated in this study, we would select the MP as opposed to the IT based on the pilots' subjective evaluations, and on the conceptual description of a vertical velocity instrument (a more in-depth definition is covered later in this section).

However, since the VVI main effect comparison for the objective data did not lead to any convincing interpretations, we would find it appropriate to recommend a follow up study evaluating pilot performance in a VVI intensive flying task, as a function of three types of Vertical Velocity Indicators: (1) An Improved Tape, (2) a Moving Pointer, and (3) a Semicircular Vertical Velocity Indicator of a more conventional form, similar to the one shown in Figure 12.

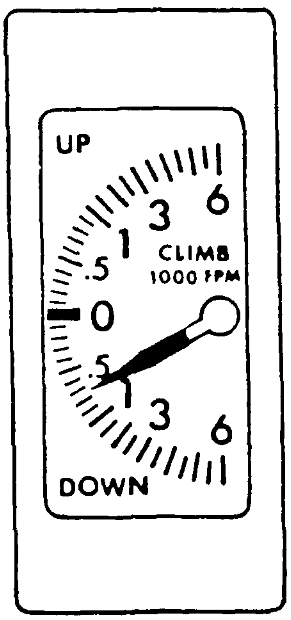

Figure 11. Semicircular VVI.

Human perception and mental representation of cockpit displays considers two significant compatibility issues (Wickens, 1984). The first component is of a static nature, which deals with the analog compatibility of orientation. In the case of the vertical velocity indication, significantly large upward and downward analog movements are most compatible with the pilots' perceptual schema. This is satisfied by all three displays under evaluation.

The second compatibility issue deals with display movements (Roscoe et al., 1981). It is proposed that an instrument's moving parts dictate the phenomenon of compatibility between the direction of movement of an indicator on a display, and the pilots' internal representation of movement. While this principle is satisfied by both the Moving Pointer and the Semicircular VVIs, a violation occurs with the Improved Tape, when the moving parts and the compatibility of orientation are opposite to each other. In order to display the numbers for high vertical velocity on top, the tape must move downward to indicate an increase in velocity. This in terms violates the principle of the moving part discussed by Roscoe. If the tape is reversed to satisfy the moving part principle, a reversal in orientation occurs with the positive high vertical velocity being indicated on the bottom.

The comparison between the Moving Pointer and the Semicircular VVIs will offer some more insight in understanding the actual mechanization of cockpit displays and their compatibilities with the pilots' mental representation. The Semicircular display may have an advantage over the Moving Pointer, in that additional information on the status of vertical velocity is being presented by a change in the pointer's angular reference.

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APPENDIX A: PERSONAL DATA

SUBJECT # ________

PERSONAL DATA

NAME ______________________ **RANK** ____________

Duty AFSC ________ **Duty Title** ______________________

AERO RATING ________________ **AGE** ______________

ORGANIZATION ________________ **OFFICE SYMBOL** ________

DUTY STATION/ZIP CODE ______________________________

DUTY PHONE (Commercial) ____________ (Autovon) ____________

Visual Acuity

Is your vision _____UNCORRECTED or _____ CORRECTED?

Do you wear glasses to fly? _____ YES _____ NO

If you know what your uncorrected visual acuity is, and you are willing to disclose the information, please write it on the lines below.

____

We are interested in an approximate history of your flying experience starting with your most recent flying experience and working back.

Aircraft	**Highest crew position**	**Hours**
______	______________________________	____________
______	______________________________	____________
______	______________________________	____________
______	______________________________	____________
______	______________________________	____________
______	______________________________	____________
______	______________________________	____________
______	______________________________	____________
______	______________________________	____________
______	______________________________	____________

Total hours instrument time _______

Total hours hood time _______

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APPENDIX B: PILOT QUESTIONNAIRE (RESULTS)

PILOT QUESTIONNAIRE

For purposes of this evaluation, we have used two vertical velocity indicators equally during the data flights. One of the displays is an "improved version" of the standard F-16 display which has been painted in a different color scheme and re-scaled to reduce the range of movement for a given change in vertical velocity. The other locally manufactured VVI display was installed to allow evaluation of a more conventional moving-pointer VVI display concept. The following questions address your feelings with regard to the moving pointer concept vs the moving tape currently in the F-16.

1. Which display do you prefer to use?

Moving pointer __6__

Moving Scale __1__

2. How much better do you feel that the display you selected is as compared to the other?

1	2	3	4	5	6	7	8	9	10
X		X			X	XX		XX	

about the same — much better — very much better

3. Did you encounter any significant problems when using the test (moving pointer) display?

Yes 4 No 3

If your answer is yes, what was the problem?

a. Scaling 2

b. Pointer Sensitivity 1

c. Instrument Size 1

d. Pointer Size ____

e. Direction of movement ____

4. Did you encounter any significant problems when using the F-16 (moving scale) display?

Yes 5 No 2

If your answer is yes, what was the problem?

a. Scaling 1

b. Pointer Sensitivity 2

c. Instrument Size ____

d. Pointer Size ____

e. Direction of movement 2

For purposes of this this study we have used two attitude indicators: the F-16 AI presenting raw ILS localizer and glideslope deviations on the pitch and bank steering bars and a bona-fide ADI presenting Flight Director steering in a conventional manner. Differences between the two displays, other than steering bar operation are as follows:

a. Sky/ground colors on the F-16 display are blue/brown, respectively. The ADI is colored gray/black.

b. Steering bars are orange on the F-16 display and light gray on the ADI.

c. The miniature aircraft and steering bars on the ADI are thinner than those on the F-16 display.

5. How would you rate your precision on an ILS approach using the ADI (with command steering) as compared to the F-16 A/I with raw ILS data?

X				XXXX	XX
0	1	2	3	4	5
much less accurate	less accurate	slightly less accurate	slightly more accurate	more accurate	much more accurate

6. How would you rate your overall workload on an ILS approach using the ADI (with command steering) as opposed to the F-16 A/I with raw ILS data?

XX	XXXX				X
0	1	2	3	4	5
much less workload	less workload	slightly less workload	slightly more workload	more workload	much more workload

7. What color scheme do you prefer on the attitude sphere?

Blue/Brown 3

Gray/Black 4

8. Steering bars on the test ADI were considerably narrower than those on the F-16 attiude indicator. Which would you prefer?

Thinner than ADI 2

Same as ADI 5

Same as F-16 A/I ____

Thicker than A/I ____

9. How do you rate the location of flight instruments in the F-16 for precision flight in a radar vector pattern and an ILS final approach?

About right 1

Too low 3

Much too low 2

10. How do you rate the location for flight instruments in the F-16 for precision flight in the transition to visual for landing from an ILS approach?

About right	1	F-16A
Too low	3	F-16C
Much too low	4	-----

11. Did you learn anything new about Flight Director operation/approach procedures while here?

Yes 3 No 4

The remainder of this questionnaire deals with the simulation itself.

12. How does this visual system (NVS) compare with the on in your simulator form the standpoint of fidelity?

Better	1
About the same	1
Worse	1
No visual system	4

13. Do you feel that the simulator training (approach and transition to visual) you received here will be beneficial to you in the F-16?

Brief/Debrief		Simulator	
Yes	1	Yes	4
No	1	No	
Maybe	1	Maybe	1

14. Please rate overall CSDF simulator (F-16) operation.

Excellent	5
Good	1
Fair	1
Poor	

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APPENDIX C: PRE-EVALUATION TRAINING

FLIGHT DIRECTOR OPERATION

Flight Director systems (Command Steering and instrument arrangements) were developed in the mid-fifties to make the pilots's job easier on ILS final approach. As these systems evolved over the years, other features, such as altitude hold, VOR and TACAN steering and others were added to expand the range of system utility.

Over the years, a number of changes have been made to the way that Flight Director calculations are made, and like almost everything else electronic, the transition has been made from analog to digital computations. Additionally, early systems were essentially stand alone, packaged in a standard container and wired into the display system. Today the calculations are imbedded in the Fire Control Computers, HUDs and Mission Computers. What is most important to the pilot, however, is that Flight Director information and the way it is used has changed only slightly. What Flight Director designers tried to do was to combine the variety of information a pilot uses to fly a raw data ILS into attitude commands for the two (pitch and roll) primary axes. Their goal was to provide a command that would - if flown properly- command pitch and bank attitudes, required to intercept and maintain the localizer and glideslope from about 10 miles from the runway to a point approximately 1/2 mile from touchdown and 200 feet above the ground. Beyond this point, the commands become quite sensitive (especially in pitch) and can lead to over controlling. Actually, the commands are valid to much lower altitudes if they are used by a skilled and proficient pilot.

To use a Flight Director successfully requires a little understanding of how they work and some prior planning. First, they are very nondiscriminating. Roll axis calculations look only at heading, the heading selected for final approach (called course and course error), localizer deviation and roll attitude. If the proper final approach course has been selected and the aircraft is left of the localizer, the system will command a right turn. The opposite is true if the aircraft is right of course. Figure C-1 shows some steering possibilities.

Note that all commands lead to a turn to a 45 degree (course cut) localizer intercept. Note also that it is up to the pilot, the published approach procedure or a radar controller to position the aircraft such that the intercept takes place at the proper location on final approach. The system doesn't care where you intercept the localizer, only that it happens.

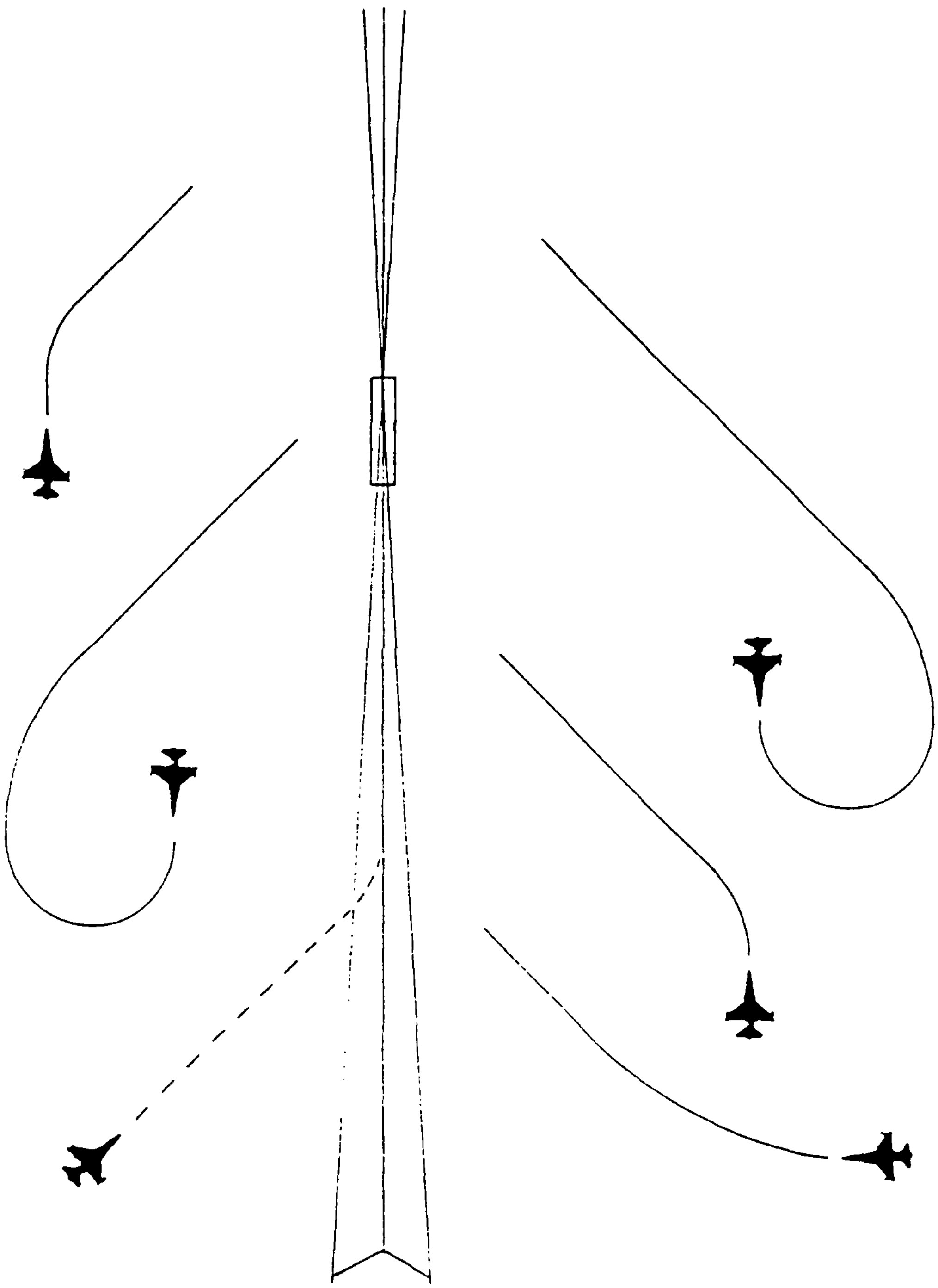

Figure C-1. Flight Director steering possibilities.

Heading is critical also. The system does not figure out the best way to turn to intercept the localizer until the airplane is pointed toward the extended runway centerline and within about 90 degrees of the selected final approach course. If you insure that you are a a reasonable distance from the airport and on a heading compatible with steering calculations, the system starts to look smart.

If you have done everything right to the point where the aircraft is on a 45 degree intercept with wings level, the Flight Director will command a bank to turn to and align with the final approach fairly close to the centerline. In this initial approach mode, the system will command bank angles compatible with normal maneuvering (25-35 degrees) for approach. In the case of the F-16 its 35 degrees.

After initial localizer capture, the calculations in some systems (F-16, F-15, C-141 etc.) try to compensate for crosswinds by electronic means so as to avoid a downwind standoff.

As the aircraft approaches the glideslope, either the pilot (T-38, T-39, and other older airplanes) or the system, through the use of glideslope beam and other sensors (F-16,C-141, C-5), must select the final approach steering mode. This mode normally provides smarter steering commands in the roll axis and a pitch command to intercept and maintain the glideslope.

Roll commands on final approach are limited to 15-20 degrees (15 in the F-16) to add additional roll attitude stability and to avoid overshooting. On final approach there are automatic crosswind calculations so that the aircraft stabilizes on a heading, and steering commands are based on a heading, compatible with what is required to remain on the runway centerline.

Pitch axis steering on the final will command pitch attitudes required to keep the airplane on the glideslope. Pitch calculations are less discriminating than roll, due to the fact that there is no selected glideslope angle similar to the selected final approach course in roll. Basically pitch commands are calculated using glideslope deviation and "washed out" pitch attitude. Washed out refers to the fact that the current pitch command is faded out over about a 10 second time period while the calculations continuously try to look for another commanded attitude. As a result, it is not too difficult to get into a chasing mode that will lead to oscillating through the glideslope. Careful use of the vertical velocity indicator and the glideslope deviation indicator will help if this occurs. A much better parameter is the flight path display on the HUD. This display can be used as required to maintain (match) or correct to the published glideslope angle.

The following diagram provides a simple flow chart of the components of a generic Flight Director configuration (Figure C-2).

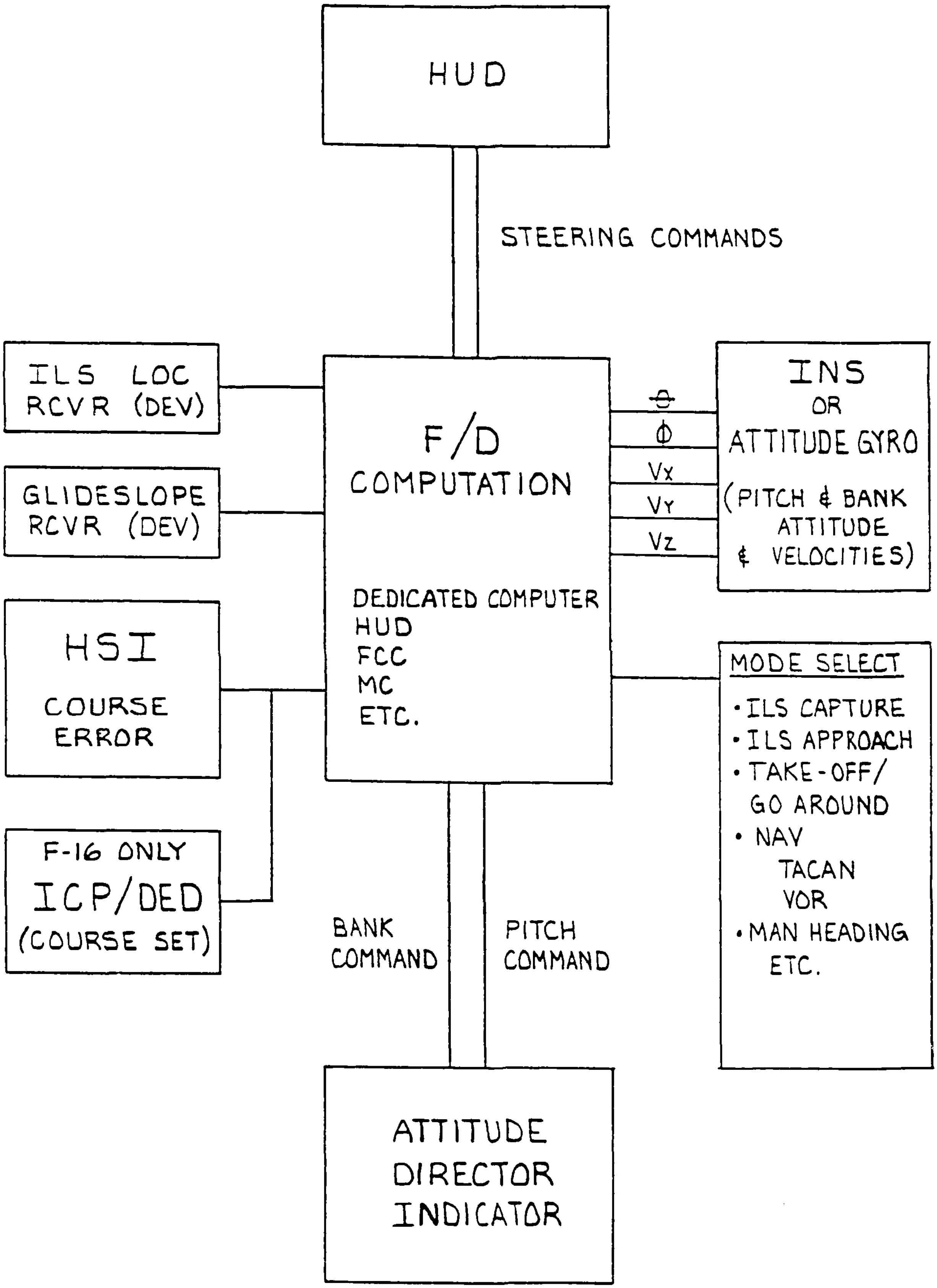

Figure C-2. Components of a generic Flight Director configuration.

PRE-EVALUATION TRAINING

Flight Director Flying Techniques

The following are a few procedures and techniques that might prove helpful when using a Flight Director in a precision approach.

1. Set the system up properly.

a. Tune to be sure you have a good signal and the right facility.

b. Select the published final approach course. In the F-16 you have to do this twice: once for the HUD and Flight Director (on the ICP/DED) and once to have the right picture on the HSI.

c. Check the glideslope angle on the approach chart. Knowing what it is will be extremely helpful when using the HUD (flight path angle) and it will help some in estimating what will be seen on the VVI during the approach.

2. Position the aircraft properly

a. Know where you are. Keep track of distance from the runway and possible or probable intercept angles.

b. Watch speed and configure for landing early enough to avoid a last minute rush.

c. When cleared for the approach, be sure the aircraft is inside Flight Director steering limits (i.e. within 90 degrees of final approach course); if not, ask the controller for vectors.

3. Fly the steering commands.

a. If the bank command is centered, the aircraft will intercept the glideslope.

b. Never trust anything; crosscheck bank attitude, heading, and CDI displacement to be sure the command is accurate.

c. Anticipate glideslope intercept. Check final approach speed (AOA), configuration and glideslope deviation indicator closing to on glideslope.

4. Transition to glideslope and final approach mode.

a. Adjust power/configuration, cleck flight path angle or vertical velocity - fly the pitch command.

b. Never trust anything; crosscheck pitch, FP, V/V, and glideslope deviation to be sure the pitch command are accurate. You

can usually help stability in the pitch axis by using the glideslope indicator (trends) FP, and vertical velocity to anticipate changes in the pitch steering command.

5. Stabilize the approach.

a. The first 3 1/2 miles of an approach are used to stabilize the aircraft on the localizer and glideslope.

b. Work on following FD commands, set and maintain desired airspeed (AOA) and make small power adjustments; trim to hands off if possible.

6. Transition to visual.

a. Expect some confusion as the visual segment grows from the first approach lights to a full perspective of the landing situation.

b. Use first indications of the runway environment only as another instrument in the crosscheck. Ceiling and visibility conditions frequently make the approach lights and touchdown zone appear, disappear, and look out of proper perspective. The instruments show how well you have flown the approach.

c. Be patient. If the approach is flown properly, all that should be required is the flare and power reduction. Reliable cues usually appear in the following order; lateral (approach lights), vertical (VASI or appearance of tourhdown zone lights), and finally, full visual perspective (you can confirm alignment, drift, sink rate, etc.).

7. Flare and touchdown.

a. Check altitude as the aircraft approaches the overrun. It should be about 100 feet AGL (radar altitude is very helpful here).

b. Don't try to land on the end of the runway if it's raining - concentrate on the landing itself.

c. Use the bank steering command through the flare unless de-crab is required. Check flight path/vertical velocity to be sure sink rate is about right for touchdown. The transition to visual should be made gradually after you confirm that what you are seeing is right; it may not be complete until the wheels are on the ground.

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